IN THE DRAWINGS:

The attached sheet of drawings includes changes to FIGs. 1-6. These sheets replace the original sheets that included FIGs. 1-6.

REMARKS

The specification and drawings have been amended following translation of the application from German to English. Claims 1-16 have been amended and claims 17-20 have been added. Claims 1-20 remain for consideration. No new matter has been added.

Examination on the merits is respectfully requested.

If a telephone interview could assist in the prosecution of this application, please call the undersigned attorney.

Respectfully submitted,

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~~Method~~ METHOD AND CIRCUIT FOR GENERATING AN AUXILIARY SYMBOL FOR ADJUSTING A QAM DEMODULATOR~~and Circuit for Generating an Auxiliary Symbol for Adjusting a QAM Demodulator~~

PRIORITY INFORMATION

This application claims priority from International application PCT/EP03/11099, filed October 8, 2003 and German application 102 49 492.4, filed October 24, 2002.

BACKGROUND OF THE INVENTION

This invention relates in general to digital signal processing and in particular to generating an auxiliary symbol in place of a decision symbol for adjusting a QAM demodulator as a part of a receiver in which the decision-feedback loops are not yet synchronized.

~~This invention relates to a method and a circuit for generating an auxiliary symbol which serves to more quickly bring d~~Decision-feedback loops utilized in quadrature amplitude modulation (QAM) receivers typically need to be quickly brought into synchronization or "lock" when digital signals locked to a quadrature signal pair are received. Such loops are used, for example, for the adjustment of sampling instants, for the adjustment of an equalizer that removes linear distortion during the reception of the quadrature signal pair, or in an automatic gain control circuit to adapt the received signals to the dynamic range. ~~The invention relates in particular to the operating state of the receiver in which the carrier and phase-locked loops of the local oscillator are not yet locked.~~

In encoded form, these digital signals, which may ~~are~~ also be referred to as symbols~~.~~, may represent a single-bit ~~one-digit~~ or multiple-bit ~~multidigit~~ binary value. Encoding for transmission may be ~~is~~ accomplished via the quadrature signal pair, which corresponds to a vector that at given instants of time takes up discrete positions in the amplitude and phase space of the

quadrature signal pair. These instants of time typically follow each other at equal intervals and generally are sampled ~~must be hit~~ by the sampling clock pulses as precisely as possible. Besides QAM, another typical ~~These~~ transmission methods is ~~are known as .quadrature amplitude modulation. (QAM) and .~~phase-shift keying~~.~~ (PSK).

In a conventional receiver for receiving digital signals, a complex multiplier or mixer, which may be ~~is~~ controlled by a local oscillator, may downconvert~~s~~ the received QAM signal, which may be ~~is~~ modulated onto a carrier frequency for transmission, to the baseband frequency. If digital signal processing is used, this downconversion can take place prior to or after analog-to-digital ~~A/D~~ conversion, ~~(A/D = analog-to-digital),~~ with the signal advantageously being sampled and digitized at the symbol rate or a multiple thereof. If the digitization rate is an even-numbered multiple of the symbol rate, each of the symbol clock pulses typically coincides ~~exactly~~ with a ~~real~~ sample value. The digitization rate may ~~is~~ advantageously be locked to the recovered symbol rate via a phase-locked loop ~~(= PLL)~~. Instead, ~~I~~if the digitization rate is free running in relation to the ~~necessary~~ symbol rate, the symbol may be ~~is ultimately~~ formed as time information via an all-digital sample-rate conversion. In this manner, a temporal interpolation between the digitized sample values of the received digital signal may be ~~is~~ controlled. Automatic gain control circuits help to achieve a relatively high utilization of ~~ensure that~~ the respective dynamic range ~~is fully utilized~~ and to map ~~that~~ the received symbols ~~are correctly mapped~~ onto the symbol decision stage. An adaptive equalizer typically reduces intersymbol interference, which may result~~s~~ from linear distortion caused by the transmitter, the transmission path, or the receiver.

In prior art ~~high-quality~~ demodulators for QAM or PSK signals, ~~that are based on the prior art,~~ the circuits for controlling the frequency and phase of the local oscillator~~,~~ (e.g., the automatic gain control, the symbol clock recovery, and the adaptive equalizer) typically look at

the differences between the received symbol and that element of the predetermined symbol alphabet which may be ~~is~~ regarded by a decision stage as the most probable symbol that matches the received symbol. This type of control over the decision symbol is usually referred to as decision-feedback control. Since in prior-art digital demodulators the decision-feedback loops are coupled together, bringing these loops into a synchronization or lock condition may be ~~is~~ difficult to achieve in a relatively rapid timeframe as long as the control for the carrier of the local oscillator~~, which downconverts the received signal to baseband,~~ is not yet stable in frequency and phase.

Frequently, the synchronization or lock condition of the decision-feedback loops can ~~only~~ be achieved if the respective frequencies and phases are relatively close to their desired values. Examples of decision-feedback loops are found in a book by K. D. Kammeyer, “~~.~~Nachrichtenübertragung”~~.~~, published by B. G. Teubner, Stuttgart, 2nd edition, 1996, pages 429 to 433, in Chapter 5.7.3, “~~.~~Adaptiver Entzerrer mit quantisierter Rückführung~~.~~”, pages 200 to 202, in Chapter 5.8.3, “~~.~~Entscheidungsrückgekoppelte Taktregelung~~.~~”, pages 213 to 215, and in Chapter 12.2.2, “~~.~~Entscheidungsrückgekoppelte Trägerphasenregelung im Basisband~~.~~”, pages 429 to 431.

What is needed is a QAM demodulator that utilizes a relatively more reliable auxiliary symbol instead of a relatively less reliable decision symbol to adjust the decision-feedback loops within the demodulator. ~~It is an object of the invention to provide an improved method and circuit which decouples decision-feedback loops in a digital-signal receiver from each other, whereby rapid acquisition is made possible for the sampling clock, the equalizer, or the amplification regardless of the frequency and phase of the local oscillator.~~

SUMMARY OF THE INVENTION

~~According to the features of the independent claims 1 and 11, the object is attained essentially by making available, during the adjustment phase of the decision-feedback loops, an~~ In a QAM demodulator, an auxiliary symbol may be utilized in place of ~~which replaces~~ the decision symbol to adjust the decision-feedback loops within the demodulator. For the formation and definition of the auxiliary symbol, the radius and angle information of the received signal or of the preliminary symbol may be ~~is~~ used. Through use of the auxiliary symbol instead of the decision symbol, any ~~The~~ error in the angle information due to the unknown frequency and phase deviation of the local oscillator may be ~~is deliberately~~ ignored. ~~This is achieved by providing a~~An auxiliary ~~-~~symbol generator may be provided ~~decision facility~~ which, instead of assigning to the received signal an element from the predetermined symbol alphabet, generates an auxiliary symbol that lies on the most probable one of the ~~possible~~ nominal radii. The term ~~. N~~nominal radii~~.~~ as used herein may mean~~s~~ those radii on which in QAM the predetermined symbols of the alphabet lie in the plane determined by the quadrature signal pair. For ~~As~~ the angle component of the auxiliary symbol, the angle information of the sampled digital signal may be ~~is~~ used. In polar coordinates, the auxiliary symbol may thus correspond~~s~~ to the vector intersection point of the sampled digital signal with the most probable nominal radius.

The decision as to which nominal radius may be ~~is~~ the most probable may be ~~is~~ made via range limits which for example may be ~~in the simplest case are~~ determined by the possible radii of the respective QAM standard, in particular ~~namely~~ by defining limit radii. These limit radii may form annuli of different widths in the quadrature signal plane which may contain one nominal radius each. It is also possible for the range limits to be determined not only by the nominal radii but also by the positions of the~~o~~se elements in the quadrature signal plane. ~~which~~

~~have to be taken into account.~~ In that case, the range limits may no longer define ~~ideal~~ annuli but may ~~more or less~~ distort the annuli~~latter~~. This may mean~~s~~, however, that the respective angle information may influence~~s~~ the auxiliary symbol decision, but ~~only~~ with little weight. Furthermore, entire regions of the quadrature signal plane can be excluded from the auxiliary decision (i.e., "masked out") because their evaluation may be ~~is too~~ uncertain.

As discussed herein, a ~~In a preceding step it is~~ determination of ~~ed~~ where the individual nominal radii and range limits lie may be made, so that the most probable nominal radius can be selected. ~~For the case w~~Where the auxiliary symbol decision may be ~~is~~ made via the most probable nominal radius using ~~through pure~~ annuli, the radii limits may be ~~are~~ determined, which advantageously may lie midway between two adjacent nominal radii. ~~Whether t~~The respective radii or range limits may be ~~are~~ retrieved from a table or may be ~~whether they are~~ continuously recalculated in accordance with the transmission standard.~~, is of secondary importance.~~

In higher-order QAM, some of these annuli may be so narrow that their evaluation in the presence of usual interference may be ~~is~~ uncertain. However, since the ~~Since, on the other hand, their~~ contribution of these annuli to the control process may be relatively ~~is~~ small, this uncertainty may be of little or no consequence. ~~is hardly disturbing.~~ Nevertheless, ~~T~~the effect of the ~~such~~ uncertain annuli can be further reduced by suitable weighting of the control information, or these annuli may be ~~they are completely~~ masked out. Furthermore, annuli can be permitted which enclose the respective nominal radius more narrowly and thus cover it with relatively greater certainty.

If the measured radius lies outside these narrower radii limits, no auxiliary symbol may ~~will~~ be defined ~~formed~~, due to the relative ~~because this would be too~~ uncertainty.

For a received digital signal with the quadrature components I = R cos α ~~a~~ and Q = R sin α ~~a~~ that falls into an annulus of nominal radius Rsi, an ~~the~~ auxiliary-symbol generator ~~decision facility~~ may form~~s~~, at the position with the nominal radius Rsi and the angle α ~~a~~, an auxiliary symbol with the polar coordinates Rsi, α ~~a~~. For ~~In order that~~ the~~is~~ auxiliary symbol to ~~can~~ be used ~~as a .decision symbol.~~ by the decision-feedback loops of the clock recovery, gain control, and/or equalizer, the ~~its~~ quadrature components I_h = Rsi cos α ~~a~~ and Q_h = Rsi sin α ~~a~~ of the auxiliary symbol may be ~~are~~ formed.

The radius R and the angle α ~~a~~ of the auxiliary symbol may be ~~are~~ determined mathematically from the quadrature components I, Q as follows:

$$R = \cancel{v}\sqrt{(I^2 + Q^2)}$$

$$\alpha\ \cancel{a} = \arctan(Q/I)$$

There are also resolvers which may convert from Cartesian coordinates to polar coordinates using ~~in an~~other methods ~~manner~~. In the digital signal processing portion of such resolvers, the ~~.~~Cordic~~.~~ technique may be ~~is usually~~ employed, as ~~because~~ it uses ~~only~~ binary additions and multiplications~~,~~ which can be implemented by simple arithmetic shifts. Furthermore, other approximation methods or tables are possible. For the inverse conversion, ~~too,~~ i.e., for the conversion from polar signal components R and α ~~a~~ to their quadrature components I = R cos α ~~a~~ and Q = R sin α ~~a~~, a Cordic converter, a table, or an approximation method can be used.

~~The invention and advantageous developments will now be explained in more detail with reference to the accompanying drawings, in which:~~

These and other objects, features and advantages of the present invention will become more apparent in light of the following detailed description of preferred embodiments thereof, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG.~~ig.~~ 1 illustrates ~~shows~~ the positions of the 16 symbols in the I/Q quadrature plane for a 16-QAM signal;

FIG.~~ig.~~ 2 is a graph of ~~shows~~ a Nyquist pulse with synchronized sampling;

FIG.~~ig.~~ 3 is a graph of ~~shows~~ a Nyquist pulse with nonsynchronized sampling;

FIG. ~~ig.~~ 4 illustrates ~~shows~~ the positions of 16 symbols of a 64-QAM signal in the first quadrant;

FIG. ~~ig.~~ 5 is a block diagram of an ~~first~~ embodiment of a demodulator with an auxiliary-symbol generator ~~in accordance with the invention~~; and

FIG.~~ig.~~ 6 is a block diagram of another ~~second~~ embodiment of a demodulator with an auxiliary-symbol generator ~~in accordance with the invention~~.

DETAILED DESCRIPTION OF THE INVENTION

Referring to ~~In~~ FIG~~ig~~. 1, a plane in which the positions of the 16 symbols $S_{ms,nm}$ of a 16-QAM signal are marked may be ~~is~~ determined by a quadrature signal pair I, Q. The designations of the individual symbols $S_{ms,nm}$ differ from each other by the specifications of the respective Cartesian coordinates. The symbol $S_{-3,1}$, for example, has the value -3 as the I-coordinate and the value 1 as the Q-coordinate. FIG. 1 ~~The diagram~~ also illustrates ~~contains~~ three circles K_1, K_2, and K_3, on which the 16 symbols $S_{m,n}$ may be ~~are~~ located. Associated with the circles may be ~~are~~ the

exemplary radius values of $R_1 = 1.41$, $R_2 = 3.16$, and $R_3 = 4.24$, which may be ~~are~~ calculated starting from the origin. To define each of the 16 symbols $S_{m,n}$ via their corresponding polar coordinates R, α ~~a~~, the respective angle components α ~~a~~ may be utilized~~are necessary~~; for the symbols $S_{3,1}$, $S_{3,3}/S_{1,1}$, and $S_{1,3}$, for example, the angles are α ~~a~~ = 18.3°, α ~~a~~ = 45°, and α ~~a~~ = 71.7°, respectively. The circles and associated radii on which the 16 symbols $S_{m,n}$ are located in FIG. 1 according to the respective transmission standard may ~~will henceforth~~ be referred to hereinafter as nominal circles and nominal radii ~~Rs~~, respectively. ~~To simplify the notation, the index notation of the designations and reference characters will be abandoned.~~

The graphs of FIGs~~igs~~. 2 and 3 each illustrate ~~show~~ the signal s of a single Nyquist pulse sn. The continuous line represents the analog waveform of the digital signal, which may typically be ~~is~~ transmitted as a continuous signal. A typical feature of the Nyquist pulse sn is that the signal may pass~~es~~ through zero at all symbol sampling instants t/T = +/- n (n = 1, 2, 3...) and that the signal ~~it~~ may equal ~~has a nonzero value, namely~~ the actual symbol value S~~,~~ ~~only~~ at the symbol sampling instant t/T = 0. If the ~~analog signal S or the~~ Nyquist pulse sn is sampled and digitized at an integral multiple of and synchronously with the symbol sampling rate ts as shown in FIG~~ig~~. 2, ~~exactly~~ the sample value at the instant t/T=0 may ~~will~~ provide the actual digital symbol S~~state~~. The sample values between the symbol sampling instants t/T = +/- n, for example ~~instance~~ at t/T = -0.5 or t/T = 1.5, may be ~~are~~ insignificant for ~~the symbol~~ recognition of the actual symbol S and can be ignored.

However, a ~~Things are~~ different result may be achieved if the Nyquist pulse sn is sampled and digitized as illustrated ~~shown~~ in the graph of FIG.~~ig~~ 3. There, ~~Here~~ the sampling and digitization clock td may be ~~is~~ synchronized with the symbol sampling clock ts neither in frequency nor in phase. Hence, the sampling instants td for the digitization may coincide with

one of the regular symbol sampling instants t/T by chance, ~~only accidentally~~ if at all. Accordingly, reliable sensing of the actual digital symbol S ~~state~~ at the instant t/T = 0 by means of the existing sample values may ~~is~~ not occur~~readily possible~~. In that case, ~~Here,~~ symbol sampling devices may be ~~are~~ necessary which perform a temporal interpolation of the ~~real~~ sample values to determine the sample value at the instant t/T = 0 as precisely as possible. Due to ~~Because of~~ the relatively narrow Nyquist pulse, which may have ~~has first~~ zero crossings at t/T = -1 and t/T = +1, ~~it is advisable to use~~ interpolation methods of higher order may be used~~,~~ so that the pulse peak S at t/T = 0 may ~~will~~ be reliably detected. The small round circles illustrated in FIG~~ig~~s. 2 and 3 correspond to the ~~real~~ sample values sampled in accordance with the sampling and digitization clock td, whereas~~.~~ t~~T~~he small squares illustrated in FIG~~ig~~. 3 correspond to interpolated sample values that correspond to the symbol sampling clock ts, these sample values~~,~~ ~~which~~ may be ~~are~~ available as data for further processing. During the transmission of a digital data stream, the individual Nyquist pulses sn may be ~~are~~ combined and transmitted as I and Q components.

FIG~~ig~~. 4 illustrates ~~shows~~ in the I/Q plane the ~~16~~ positions of the 16 symbols $S_{m,n}$ of a 64-QAM signal in the first quadrant.

~~For the acquisition process according to the invention i~~It is generally irrelevant which quadrant the 64 elements $S_{m,n}$ of the symbol alphabet are located in. For example, ~~I~~in the case of symbol $S_{7,7}$, the symbols $S_{-7,7}$, $S_{-7,-7}$, and $S_{7,-7}$ located in ~~of~~ the three other quadrants may be ~~have been~~ added in parentheses by way of illustration. ~~The diagram of~~ FIG~~ig~~. 4 illustrates ~~shows~~ for the individual symbols $S_{m,n}$ the Cartesian coordinate grid determined by the two quadrature signal components I, Q.

The horizontal and vertical illustrated grid lines may be ~~are~~ defined by a scale of from 0 to 8 on each of the two coordinate axes I, Q. ~~The diagram of~~ FIG~~ig~~. 4 also illustrates a number of ~~contains~~ nominal circular arcs Rs ~~which belong to the first quadrant~~ that ~~and~~ pass ~~exactly~~ through the corresponding 16 symbols $S_{m,n}$ in the first quadrant. For the 16 symbols illustrated in FIG. 4 in the first quadrant, and hence for all 64 symbols of the QAM signal, there are nine ~~9~~ nominal arcs Rs1 to Rs9, which are illustrated in FIG. 4 ~~drawn~~ as continuous lines. Associated with each nominal arc is a nominal radius, similarly designated as Rs1 to Rs9. ~~Rsi, which is why in Fig. 4 the reference characters of the nominal radii Rs1 to Rs9 are used as reference characters for the nominal arcs.~~ Three arcs may intersect a single symbol ~~only one element~~ $S_{m,n}$ in the first quadrant. That is, a~~A~~rc Rs1 may intersect~~s~~ symbol $S_{1,1}$, arc Rs3 may intersect~~s~~ symbol $S_{2,2}$, and the outermost arc Rs9 may intersect~~s~~ symbol ~~element~~ $S_{7,7}$. All of the other arcs may intersect two symbols except for arc Rs6~~,~~ which may intersect~~s~~ three symbols.

~~Those a~~Arcs which may lie ~~exactly~~ midway between two nominal arcs may be illustrated in FIG. 4 ~~Rs are represented~~ by broken lines,~~.~~ ~~The reference characters of~~ these arcs being designated ~~run~~ from Rg1 to Rg8. ~~If f~~For a received symbol S which may differ~~s~~ from the predetermined symbol alphabet $S_{m,n}$ due for example to interference or because control loops are not locked, if a different radius ~~R~~ is measured~~, then~~ the circular arcs Rg1 to Rg8 represented by broken lines may then correspond to limit lines which include the most probable nominal radius Rs1 to Rs9. ~~Therefore, t~~The radii of these range limits may be ~~are herein~~ referred to hereinafter as limit radii Rg1 to Rg8.

The definition of the midway point ~~middle~~ between two nominal arcs as a limit radius is exemplary. ~~simple, but not mandatory.~~ For example~~instance~~, the respective limit radii may be shifted from the middle in either direction, as indicated by the dash-dot arcs in FIG~~ig~~. 4. The

limit radius Rg1', for example, may increases the detection range around the corresponding nominal radius Rs1. If the limit radius Rg2 is replaced, for example, by the two limit radii Rs2+ and Rs3-, then an annulus (illustrated with ~~shown~~ hatched lines) may be defined as being ~~is obtained~~ between these two limit radii Rs2 and Rs3 in which a decision on the most probable nominal radius may be ~~is~~ suppressed. Also, ~~T~~the limit radii Rs3- and Rs3+ may narrow down the evaluation range for the nominal radius Rs3, where~~by~~ the number of incorrect ~~wrong~~ decisions may be ~~is~~ reduced. Further, ~~B~~between the third and fourth nominal radii Rs3 and Rs4, another narrow masked-out region, which lies between the limit radius Rs3+ and the midway limit radius Rg3, may be illustrated by ~~is shown~~ hatched lines by way of example.

The nominal radii Rs6 and Rs7 may differ by a relatively small amount. ~~only little.~~ Thus, ~~It may be appropriate to exclude~~ these relatively uncertain regions may be excluded from the decision as to which may be ~~is~~ the most probable nominal radius. This region could be defined by the limit radii Rg5 and Rg7, for example.

If the selection of the most probable nominal radius Rsi is made by ~~not only via~~ the radius R and by ~~but also via~~ the angle α ~~a~~, the range limits may ~~will~~ no longer be ~~purely~~ circular arcs but may ~~will~~ deform somewhat~~more or less~~. In the vicinity of a symbol to be expected, $S_{m,n}$, the regions may ~~will~~ increase in size, and if the possible symbol $S_{m,n}$ is relatively far away in terms of angular distance, the regions may ~~will~~ decrease correspondingly.

As an example, FIG~~ig~~. 4 illustrates the formation of an auxiliary symbol Sh from a received signal s or a preliminary symbol S. Th~~is~~e preliminary symbol S has the radius component R and the angle component α and may~~a. The preliminary symbol S~~ lies within the range limits Rg5 and Rg6. Therefore, the most probable nominal radius Rsi for the symbol S is

the nominal radius Rs6. The position of the auxiliary symbol Sh may be ~~is~~ defined by the most probable nominal radius Rs6 and the existing angle component α ~~a~~.

The polar coordinates Rs6 and α ~~a~~ of the auxiliary symbol Sh can be converted into components of the quadrature signal pair I, Q with the aid of the Cartesian grid or via a suitable transformation. The auxiliary symbol Sh, except for the angle component α ~~a~~, may ~~thus~~ correspond~~s~~ to the symbols $S_{1,7}$, $S_{5,5}$, or $S_{7,1}$, which all lie on the same nominal radius Rs6. This is an essential difference from conventional symbol decision devices, which~~make essentially~~ perform a distance decision. In such distance decision devices, the preliminary symbol S may be ~~would have been~~ assigned to the symbol $S_{7,3}$ or ~~possibly to~~ the symbol $S_{5,3}$, which are both nearer than the symbols $S_{1,7}$, $S_{5,5}$, or $S_{7,1}$ on the nominal arc Rs6 and which are on arcs Rs7 and Rs5, respectively.

Referring to FIG~~ig~~. 5, an ~~shows schematically in block-diagram form one~~ embodiment of a QAM demodulator circuit 1 ~~according to the invention~~ for receiving digital signals s includes ~~, which incorporates~~ an auxiliary-symbol generator. A signal source 2, for example ~~instance~~ a tuner, may provide~~s~~ the digital signal s in a band-limited intermediate-frequency position. There it is sampled and digitized by ~~means of~~ an analog-to-digital ~~A/D~~ converter (ADC) 3. A ~~The fixed~~ digitization clock td may be ~~is~~ provided by a clock generator 4 to the ADC 3. ~~As a rule,~~ T~~t~~he digitization clock td may be ~~is~~ identical to ~~with~~ the system clock for the ~~entire~~ demodulator 1. The output of ADC~~A/D converter~~ 3 may be ~~is~~ a digitized signal sd provided ~~, which is fed~~ to a bandpass filter 5~~,~~ which removes DC components and undesired harmonics therefrom.

~~Connected to bandpass filter 5 is a~~A quadrature mixer 6~~, which~~ may downconvert~~s~~ the ~~digital signal s or~~ the filtered digitized signal sd to the baseband frequency and divide it ~~splits it up~~ into the two quadrature signal components I, Q. For the frequency conversion, the quadrature

mixer 6 may be provided ~~is supplied~~ with two carrier~~s~~ signals 90 degrees apart in phase from a local oscillator 7 whose frequency and phase may be ~~are~~ controlled by a carrier controller 8. ~~Before the quadrature signal pair I, Q is further processed, u~~ Undesired harmonics may be ~~are~~ removed from the quadrature signal pair I, Q by ~~means of~~ a low-pass filter 9. The filtered quadrature signal pair I, Q may be provided ~~is fed~~ to a symbol sampling device 10~~, which is~~ controlled by a sampling controller 11~~,~~ that ~~which~~ defines the symbol sampling instants ts (FIGs. 2, 3). ~~In the normal operating state, t~~The symbol sampling instants ts may typically be ~~are~~ determined by the symbol rate 1/T and the ~~exact~~ phase position of the received digital signal s. Since the digitization rate td may ~~is~~ not be synchronized with the symbol rate 1/T (FIG. 3), ~~in sampling device 10~~ a temporal interpolation between the ~~real~~ sample values may be ~~is~~ performed in the sampling device 10 at the symbol rate or an integral multiple thereof~~, see also~~ (FIG~~ig~~. 3).

The output of the sampling device 10 may be ~~is~~ filtered by ~~means of~~ a low-pass filter 35 with a predetermined Nyquist characteristic. The output of the filter 35 may be provided ~~, and then applied~~ to a gain-controlled amplifier 12 with feedback. The ~~A~~amplifier 12 may be ~~is~~ controlled by a gain controller 13. ~~The g~~Gain control assists with ~~is necessary to ensure that~~ the utilization of the dynamic range of a symbol decision stage 15. ~~is properly utilized.~~ After an equalizer 14, the two components of the quadrature signal pair I, Q may in general be ~~are~~ free of distortion and ~~are~~may be -available as a preliminary symbol S. From the preliminary symbols S, the symbol decision stage 15 may form~~s~~ corresponding decisions symbols Se, which may be ~~are~~ applied directly or through a multiplexer 18 to additional ~~further~~ digital signal processing devices 16 and to the decision-feedback controllers 8, 11, 13, 14 within the ~~in~~ demodulator circuit 1. Since an angle component α ~~a~~ typically may not ~~cannot~~ be dispensed with in the control process

performed in the carrier controller 8, the carrier controller 8 may ~~latter, unlike the other controllers 11, 13, 14, is~~ not be connected to a multiplexer 18.

The generation of the auxiliary symbol Sh may be performed by ~~takes place in~~ an auxiliary-symbol generator ~~decision facility~~ 17. An ~~The~~ input stage of the auxiliary-symbol generator ~~decision facility~~ 17 may comprise ~~is~~ a resolver 20 that ~~which~~ converts the sampled quadrature signal pair I, Q of~~r~~ the preliminary symbol S into corresponding polar coordinates R, α ~~a~~. A radius decision stage 21 may ~~then~~ determines the most probable nominal radius Rsi from the polar coordinates R, α ~~a~~, for example, ~~particularly~~ from the radius component R. The limit radii Rg and the associated nominal radii Rs may for example be ~~are advantageously~~ retrieved from a table 22. ~~The result of the radius decision is t~~The most probable radius Rsi, ~~which, in~~ together with the angle component α ~~a~~, may be provided ~~is fed~~ to an inverse resolver 23~~,~~ that ~~which~~ forms the corresponding quadrature components I_h, Q_h from the polar coordinates Rsi, α ~~a~~. The quadrature components of the generated auxiliary symbol may be ~~are~~ applied to one input of the multiplexer 18, whose other input may be provided ~~is fed~~ with the quadrature components of the decision symbol Se. Thus, in the adjustment phase, the controllers 11, 13 and the equalizer 14 may ~~can~~ be provided ~~fed~~ with the relatively reliable auxiliary symbol Sh instead of the relatively ~~uncertain~~ unreliable decision symbol Se.

Referring to ~~The block diagram of~~ FIG~~ig~~. 6, ~~shows~~ another embodiment of a demodulator circuit 1' ~~according to the invention~~ for receiving digital signals s~~, which~~ incorporates an auxiliary-symbol generator 17 as in FIG~~ig~~. 5. As an alternative to the sampling and digitization with a constant frequency and phase ~~fixed~~ digitization clock td according to FIG~~ig~~. 5, the demodulator circuit 1' of FIG. 6 may be provided ~~is supplied~~ with a frequency- and phase-

controlled sampling and digitization clock td' from a controlled oscillator 4'. A controller 40 synchronize~~s~~ the digitization rate td' with the symbol sampling instant t/T or a multiple thereof ~~, see also (~~FIG~~ig~~. 2). The subsequent interpolation of the quadrature signal pair I, Q in the sampling device 10 of FIG~~ig~~. 5 can thus be eliminated~~dispensed with~~. Also~~Furthermore~~, ~~even~~ the sampling device 10 ~~itself~~ may be omitted as a separate functional unit, since its function may be performed ~~is automatically taken over~~ by the equalizer 14, which may operate~~s~~ at the symbol rate 1/T. Further, ~~T~~the low-pass filter 9 after the quadrature mixer 6 may ~~is~~ no longer be utilized, as ~~necessary, either. I~~its limiting action may be ~~is~~ provided by the low-pass filter 35 with the Nyquist characteristic.

The ~~To control the controller 40, its control~~ inputs of the controller 40 may be provided ~~are fed~~ with the preliminary symbol S and, at start-up, the auxiliary symbol Sh. When the resulting digitization rate td' may be synchronized ~~is in sufficiently exact synchronism~~ with the symbol rate 1/T, switchover from the auxiliary symbol Sh to the decision symbol Se may occur ~~is effected~~ by the ~~means of~~ multiplexer 18, as also in the case of the controllers 13 and 14.

Except for the differences described, the embodiment of FIG~~ig~~. 6 may be considered to be similar ~~is identical~~ to the embodiment of FIG~~ig~~. 5. Therefore, corresponding functional units are designated by like reference characters.~~in both block diagrams, so that they need not be explained again.~~

The interface 3 for the digitization in FIG~~ig~~s. 5 and 6 may also the quadrature mixer 6, for instance if the intermediate frequency after the signal source 2 may be relatively ~~is too~~ high. The function and generation of the auxiliary symbol Sh may ~~are~~ not be directly affected thereby. Due to ~~Because of~~ the partially analog signal paths, however, errors and asymmetries may occur~~creep in~~, for example ~~articularly~~ ~~into~~ the quadrature components I, Q, which may not be removed ~~can~~

~~hardly be eliminated~~ by the equalizer 14 and thus may increase the uncertainty in the symbol recognition.

Although the present invention has been shown and described with respect to several preferred embodiments thereof, various changes, omissions and additions to the form and detail thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is: